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13. ABSTRACT (Maximum 200 words)

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This grant supported a range of theoretical work on topics in neural networks, learning theory, dynamical systems and optimization. We summarize the achievements below and give a list of the relevant publications.

(a) LIST OF ACHIEVEMENTS.

It is convenient to divide the work into four parts: (i) dynamical systems models of computation, (ii) learning and reasoning theory, (iii) clocked neural networks and quantum computing, and (iv) statistical physics models of neural networks.

1. Dynamical System Models of Computation.

We found a formalism for describing the dynamics of hybrid systems and studied their cababilities as computers. Our models allow us to look at certain basic processes such as analog to digital conversion, in an abstract way emphasizing the fact that digital representations need to be robust whereas analog ones are continuously variable. Through the study of these models we are able to see certain problems in computer science and signal processing in a common framework. We have found certain classes of differential equations with inputs whose responses have readily identifible characteristics which depend only on topological aspects of the inputs and not on the detailed behavior of the input. These systems a can be thought of as defining automata and are capable of performing certain computations in an extremely robust way. See references [1-7].

2. Learning and Reasoning Theory.

We proved that many models of reasoning, and approximate reasoning, commonly used in Artificial Intelligence are computational infeasible, in the sense of being NP-complete. We put complexity bounds on approximate reasoning for classes of propositional formulae. Learning theory was applied to learning visual concepts. A book, "Circuits of the Mind", was published describing a theory of the brain based on neuron-like elements, called *neuroids* (see reference [21]). This book emphasized the importance of considering the computational feasibility of algorithms and of exploiting the high degree of connectedness in the brain. The book included models for cognitive abilities such as learning (with or without a teacher), memorization, and reasoning. In addition it outlined the development of a theory for learning to reason. See references [8], [10-14], [16-18], [20-21].

3. Clocked neural networks and quantum computing.

We completed an analysis of a new clocked neural network architecture - competitive neural networks - optimized for visual pattern recognition. Small groups of fully interconnected electronic elements are used to recognize elemental pattern features. The state of each small group, i.t. the most favored features, are then compared over larger distances, using relatively few long range interconnections, in order to stitch together larger objects. In a series of two long papers (references [23-24]) we presented a detailed analysis of the gloabl stability of competitive networks, and analyze the performance of associative memory using this architecture. We obtained "phase diagrams" with regions of guaranteed stability, which can be used for system design. These analytical results were in good agreement with numerical stability. We constructed double and triple quantum dots with tunable coupling, using electron beam patterned gates on top of GaAs/AlGaAs heterostructures. Such devices can be regarded as artificial molecules with tuneable molecular coupling. The Coulomb blockage is used in low temperature measurments to determine the existence and energetics of melecular electronic states, whicha re superpositions of the electron states on the separate quantum dot sites. A strong splitting of Coulomb blockage conductance peaks into two (and three) peaks as the interdot tunneling is increased for double (and triple) dots confirm the existance of coherent molecular states [25]. This project is being transferred to other sources of funding. We plan measuremnets of the molecular states for other interconnection topologies, and plan to test the sensitivity of coherent states to electromagnetic radiation. See references [22-25].

4. Statistical Physics models of neural networks.

We used mean field analysis to understand the properties of texture models near their phase transitions temperatures. We developed a new appraoch to self-organization of early vision and

showed a relation to the influential work of Becker and Hinton. We showed that algorithms based on statistical physics could be applied to calculate robust principal components. We analyzed deterministic annealing, related it to other optimization algorithms, and proved convergence bounds for the linear assignment problem. We obtained convergence bounds for learning using Radial Basis functions and related networks. We showed that realistic neuronal models could act as content addressable memories. It was dmonstrated that statistical physics algorithms could be used to perform robust principal component analysis. See references [9], [15], [19], [26-32].

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